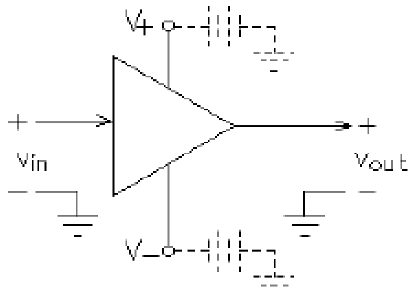
ECE2280 FUNDAMENTALS OF ELECTRICAL ENGINEERING

Amplifiers

Purpose: a weak signal is produced by a transducer (ex. Microphone) → too small for reliable processing, so amplify magnitude, i.e. make it larger

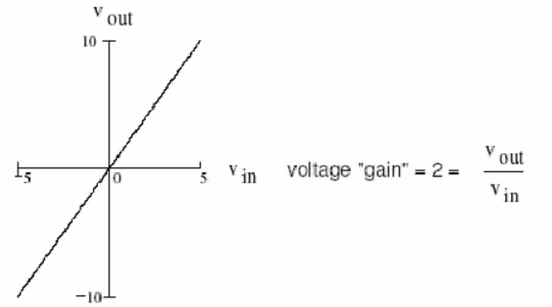
Amplifier → basic element of analog circuits



Batteries or power supplies are rarely shown on the schematic.

Signal voltages are assumed to be referenced to ground even if the grounds aren't shown.

Transfer Characteristic:

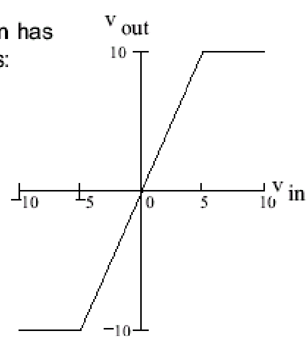


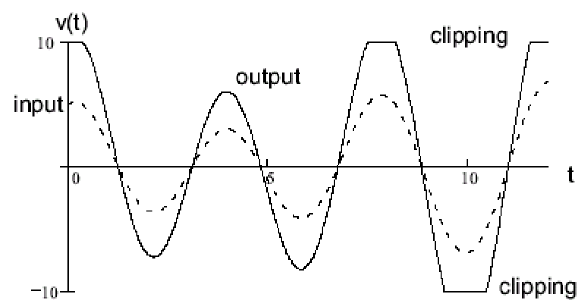
The output of all amplifiers are limited by the power supplies. Usually the limits are less than the power voltages.

Output limits, $L+ \leq V+$, $L- \geq V-$ (usually)

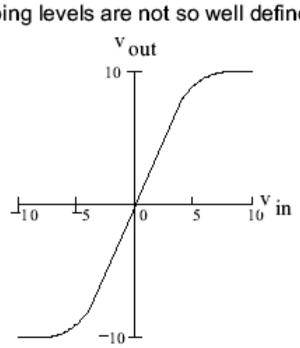
The output can't go beyond these limits no matter what the input does. If you want to avoid the "clipping" distortion in the output, you have to limit the input (make sure it's within an acceptable range).

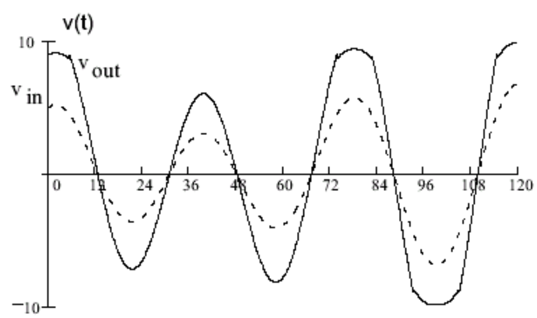
The transfer function has some non-linearities:



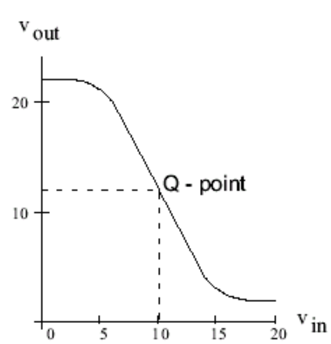


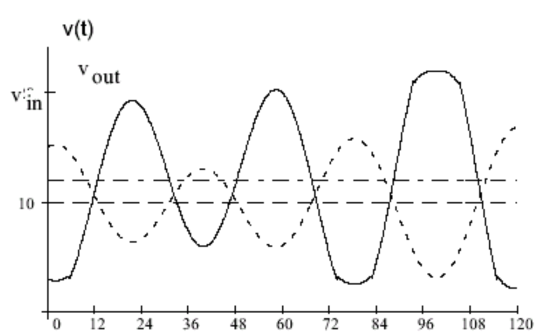
Often the clipping levels are not so well defined





Many of the transistor amplifier circuits that we'll see this semester will have DC offsets and will invert the signal.





The signal is considered the AC (changing) part of the waveform and the DC is called "bias" or the "quiescent - point" (Q - point) of the circuit.

Gain

voltage gain $= A_v = \dfrac{v_{out}}{v_{in}}$

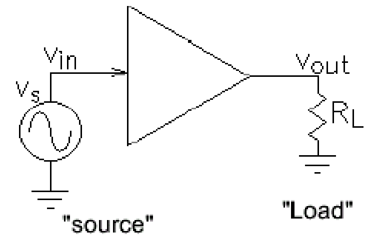
lower -case letters refer to signal values

DC: $\dfrac{V_{OUT}}{V_{IN}}$ is rarely gain

The two below require a load, otherwise there's no output current, & no output power.

current gain $= \dfrac{i_{out}}{i_{in}} = \dfrac{i_L}{i_{in}}$

power gain $= \dfrac{P_{out}}{P_{in}} = \dfrac{P_L}{P_{in}}$

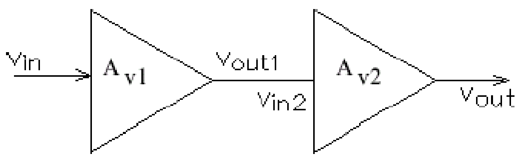


Gains are dimensionless numbers

Gain is just an idealized transfer function.

If only 1 input is shown, assume that other input is grounded.

Two stages

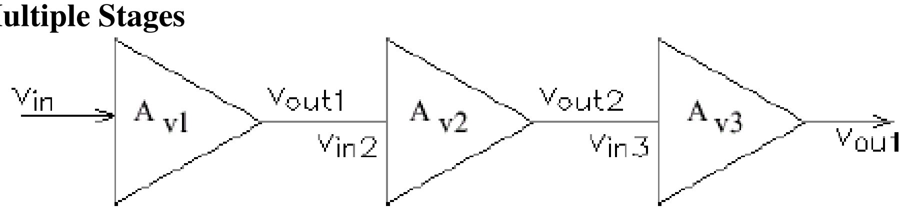


$v_{out} = v_{in2} \cdot A_{v2} = v_{out1} \cdot A_{v2} = v_{in} \cdot A_{v1} \cdot A_{v2}$

$A_{vtotal} = A_{v1} \cdot A_{v2}$

if $A_{v1} := 10$ & $A_{v2} := 4$ then $A_{vtotal} = A_{v1} \cdot A_{v2} = 40$ Same holds for multiple stages

Multiple Stages



Gain expressed as ratios: $A_{vtotal} = A_{v1} \cdot A_{v2} \cdot A_{v3}$

Gain expressed as dB: $A_{vtotal\_dB} = A_{v1\_dB} + A_{v2\_dB} + A_{v3\_dB}$

If $A_{v1} := 20$, $A_{v2} := 8$ & $A_{v3} := 4$ then $A_{vtotal} = A_{v1} \cdot A_{v2} \cdot A_{v3} = 640$

$A_{v1\_dB} := 20 \cdot \log(20)$ $A_{v2\_dB} := 20 \cdot \log(8)$ $A_{v3\_dB} := 20 \cdot \log(4)$

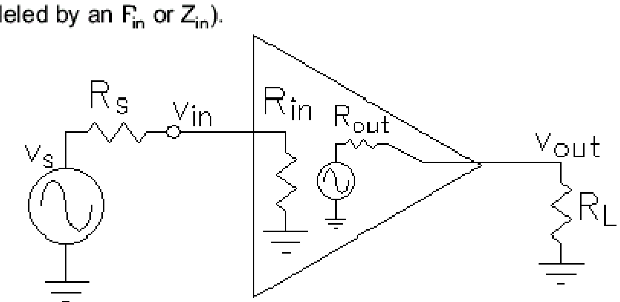
$A_{v1\_dB} = 26.021 \cdot dB$ $A_{v2\_dB} = 18.062 \cdot dB$ $A_{v3\_dB} = 12.041 \cdot dB$

$20 \cdot \log(640) = 56.124 \cdot dB$

$A_{vtotal\_dB} = A_{v1\_dB} + A_{v2\_dB} + A_{v3\_dB} = 56.124 \cdot dB$

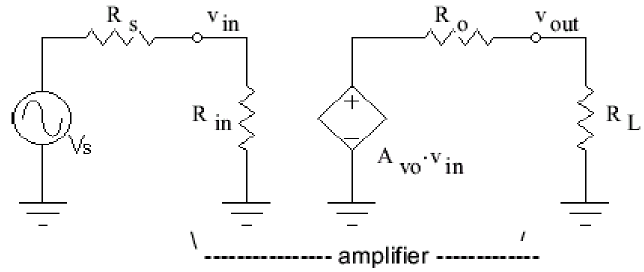
Amplifier Models

Up until now we haven't worried about the currents into and out-of our amplifiers. In reality, any source, including the amplifier, will have a source resistance (R_s or Z_s for the source and R_{out} or Z_{out} for the amp). Also any amplifier will let a little signal current flow in (modeled by an R_{in} or Z_{in}).



At this point, the triangle symbol gets to be a little cumbersome and is dropped.

Basic amplifier model:
Voltage amplifier
with source and load



Notice the dependent source inside the amplifier

A_{vo} is the "unloaded" gain or "open-circuit" gain because

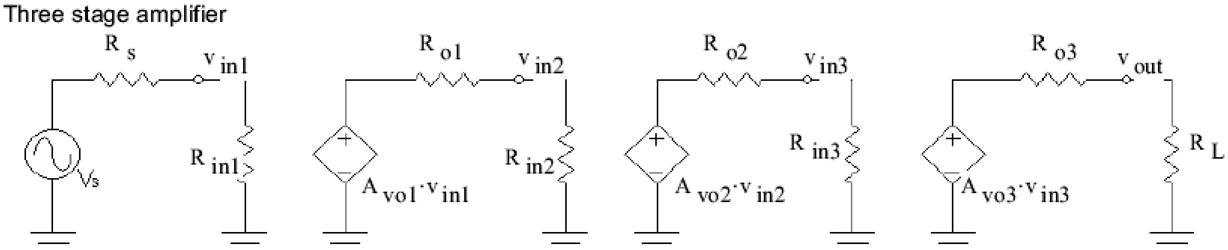
$A_{vo} \cdot v_{in}$ would be the output if there were no load resistor ($R_L = \infty$).

Overall gain: $$\frac{v_{out}}{v_s} = \frac{R_{in}}{R_s + R_{in}} \cdot A_{vo} \cdot \frac{R_L}{R_o + R_L}$$

or, in dB: $$20 \cdot \log\left(\frac{v_{out}}{v_s}\right) = 20 \cdot \log\left(\frac{R_{in}}{R_s + R_{in}}\right) + 20 \cdot \log(A_{vo}) + 20 \cdot \log\left(\frac{R_L}{R_o + R_L}\right)$$

- dB + dB - dB

Three stage amplifier



Overall gain: $$\frac{v_{out}}{v_s} = \frac{R_{in1}}{R_s + R_{in1}} \cdot A_{vo1} \cdot \frac{R_{in2}}{R_{o1} + R_{in2}} \cdot A_{vo2} \cdot \frac{R_{in3}}{R_{o2} + R_{in3}} \cdot A_{vo3} \cdot \frac{R_L}{R_{o3} + R_L}$$

Desirable characteristics

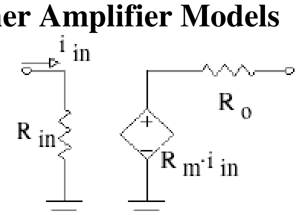
Want R_{in} --> ∞ High input resistance means the amplifier will not load down the source or previous stage.

Want R_c --> 0 Low output resistance means the amplifier supply lots of current to the load or next stage.

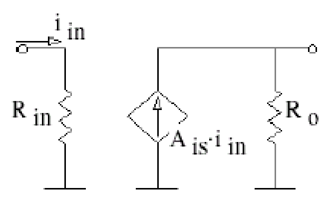
High R_{in} and low R_c means good current gain. In fact these terms are used much more often than "current gain".

At higher frequencies it may become more important to match impedances than to maximize R_{in}.& minimize R_c.

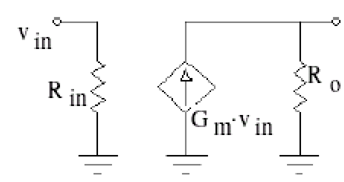
Other Amplifier Models



Transresistance amplifier



Current amplifier



Transconductance amplifier

Instead of $A_{vc} = \frac{v_o}{v_{in}}$ (unloaded)

This amp has $R_m = \frac{v_o}{i_{in}}$ (unloaded)

$\frac{V}{I} = \Omega$, that's why it's called transresistance

Insterad of $A_{vo} = \frac{v_o}{v_{in}}$ (unloaded)

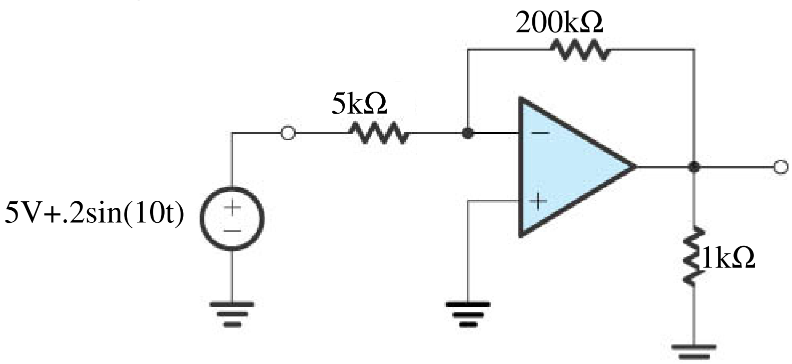
This amp has $G_m = \frac{i_o}{v_{in}}$ (unloaded)

$\frac{I}{V}$ = conductance, that's why it's called transconductance, units mho or seimen

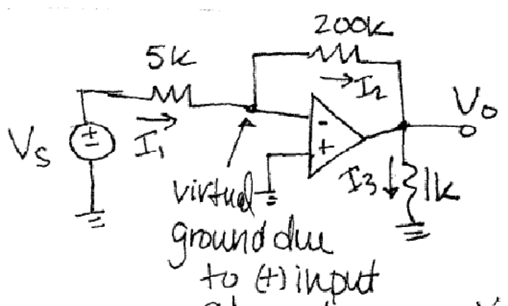
Procedure for solving ideal op-amp circuits:
1. If the noninverting terminal of the op-amp is at ground potential, then the inverting terminal is at virtual ground. Sum currents at this node, assuming zero current enters the op-amp itself.
2. If the noninverting terminal of the op-amp is not at ground potential, then the inverting terminal voltage is equal to that at the noninverting terminal. Sum currents at the inverting terminal node, assuming zero current enters the op-amp itself.
3. For the ideal op-amp circuit, the output voltage is determined from either step 1 or step 2 above and is independent of any load connected to the output terminal.

Example 12:

For the circuit below, assume an ideal op-amp. Find the currents through all branches and the voltages at all nodes. Since the current supplied by the op amp is greater than the current drawn from the input signal source, where does the additional current come from?



• The additional current is supplied from the supply power for the op amp.



$I_1 = I_2$

$I_1 = V_s/5k = \frac{5V + 0.2\sin(10t)}{5k}$

$I_1 = I_2 = 1mA + 40\mu(\sin(10t))$

$V_o = -I_2\,(200K)$

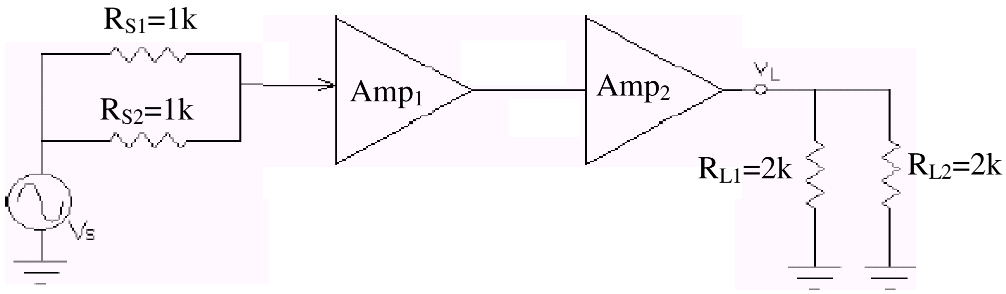
$\therefore\ V_o = -1m(200k) - 40\mu(200k)\sin(10t)$

$V_o = -200V - 8\sin(10t)$

$I_3 = \frac{V_o}{1k}$

$I_3 = -200mA - 8mA\sin(10t)$

Example 13: Use the following circuit.



You are given: Amp1 has an $A_{vo}=5$, $R_i=500$, $R_o=12k$ Amp2 has an $A_{vo}=20$, $R_i=3k$, $R_o=4k$

(a) Find $A_v = \frac{v_L}{V_S}$ Express your answer as a ratio in dB.

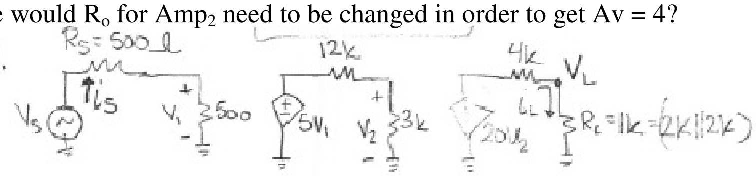
(b) Evaluate the overall current gain($\frac{i_L}{i_s}$). Express your answer as a ratio and in dB form.

(c) Evaluate the overall power gain ($\frac{P_L}{P_s}$). Express your answer as a ratio and in dB form

(d) If Vs=40mV$_{pp}$. What is the output voltage (peak-to-peak) at V_L?

(e) What value would R_o for Amp2 need to be changed in order to get Av = 4?

1.



$V_L = \frac{20V_2 \cdot 1k}{5k} = 4V_2$

$V_2 = \frac{5V_1 \cdot 3k}{15k} = V_1$

$V_1 = \frac{V_S(500)}{1k} = \frac{V_S}{2}$

$\frac{V_L}{V_S} = \frac{1k(20)}{5k}\left(\frac{3k(5)}{15k}\right)\left(\frac{500}{1k}\right) = 2\ V/V \triangleq 6dB$

(a) $\therefore V_L = 4(1)\left(\frac{V_S}{2}\right) \Rightarrow$ $\boxed{\frac{V_L}{V_S} = 2\ V/V \triangleq 6\ dB}$

Once one quantity is found, the others can be found by their relatationship to V_L and V_S ⇒

(b) $\frac{V_L}{R_L} = i_L \Rightarrow V_L = (i_L \cdot R_L)$

$V_S = i_S(1K)$

$\frac{V_L}{V_S} = 2 = \frac{i_L(1K)}{i_S(1K)}$ $\therefore$ $\boxed{\frac{i_L}{i_S} = 2\ A/A \triangleq 6\ dB}$

(c) $P_L = i_L \cdot V_L$, $P_S = i_S \cdot V_S$

$\frac{P_L}{P_S} = \frac{i_L \cdot V_L}{i_S \cdot V_S} = 2 \cdot 2 =$ $\boxed{4\ V/V \triangleq 12dB}$

(d) $V_S = 40mV_{pp} \Rightarrow \frac{V_L}{V_S} = 2$ $\therefore V_L = 2(40mV_{pp}) =$ $\boxed{80mV_{pp}}$

(e) $A_v = 4 = \frac{20 \cdot 1k}{1k + R_o}(1)\left(\frac{1}{2}\right) \Rightarrow$ $\boxed{R_o = 1500\ \Omega}$

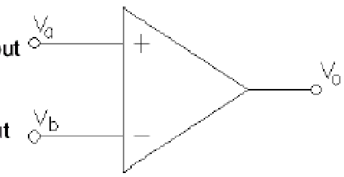
Operational Amplifier:

An operational amplifier is basically a complete high-gain voltage amplifier in a small package. Op-amps were originally developed to perform mathematical operations in analog computers, hence the odd name. With the proper external components, the operational amplifier can perform a wide variety of "operations" on the input voltage. It can multiply the input voltage by nearly any constant factor, positive or negative, it can add the input voltage to other input voltages, and it can integrate or differentiate the input voltage. The respective circuits are called amplifiers, summers, integrators, and differentiators. Op-amps are also used to make active frequency filters, current-to-voltage converters, voltage-to-current converters, current amplifiers, voltage comparators, etc. etc.. These little parts are so versatile, useful, handy, and cheap that they're kind of like electronic Lego blocks — although somewhat drably colored.

Op-amp characteristics

An op-amp has two inputs

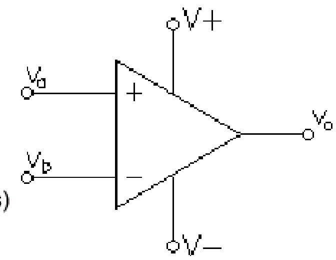
Amplifies the voltage *difference* between those two inputs.



$$v_o = G\cdot(v_a - v_b)$$

G = voltage gain of the op-amp

G is usually very big, ≥ 100,000



The op-amp must be connected to external sources of power, V+ and V-.

The output voltage is limited by the power supply voltages.

$V- \le v_o \le V+$ (Usually even more limited than this)

So: $V- \le G(v_a - v_b) \le V+$

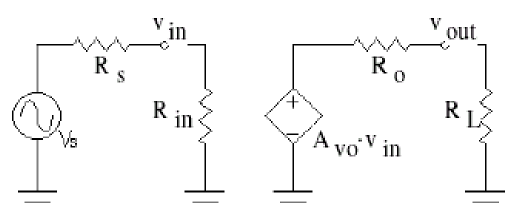
If the op amp is in its ***active*** region:

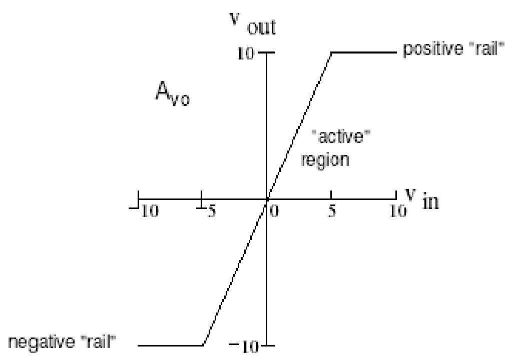
Since G is very big, $(v_a - v_b)$ must be very small, in fact the usual assumption is that

$V_a \cong V_b$ Active region ONLY

Clipping

All real amplifiers will clip the output signal if the input is too big. Only one part in the model can possible account for the clipping-- a nonlinear A_{vo}.





Clipping level at the output (v_{out}) is less than that of A_{vo} (± 10V) because of the R_c, R_L voltage divider.

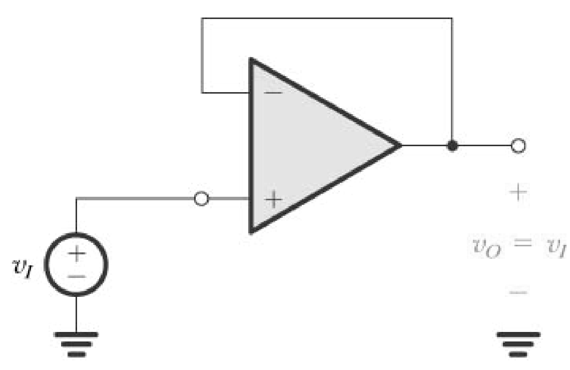
The maximum allowable $v_{in} = \dfrac{10\cdot V}{A_{vo}}$

The maximum allowable v_s is greater than this because of the R_S, R_{in} voltage divider.

Op Amp Configurations:

1. Voltage Follower => $V_o = V_i$

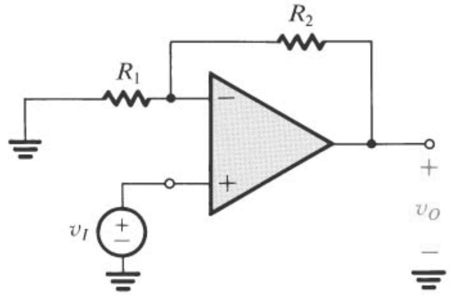
Used as a current amplifier



(a)

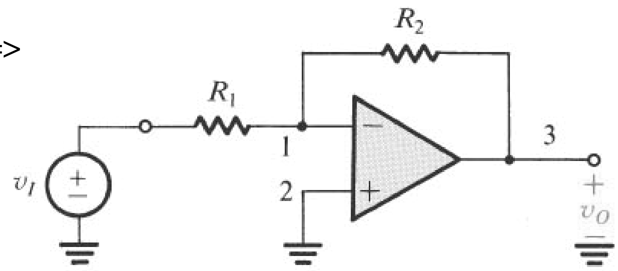
2. Noninverting amplifier =>

$$v_o = \left(\frac{R_2}{R_1} + 1\right) \cdot v_i$$



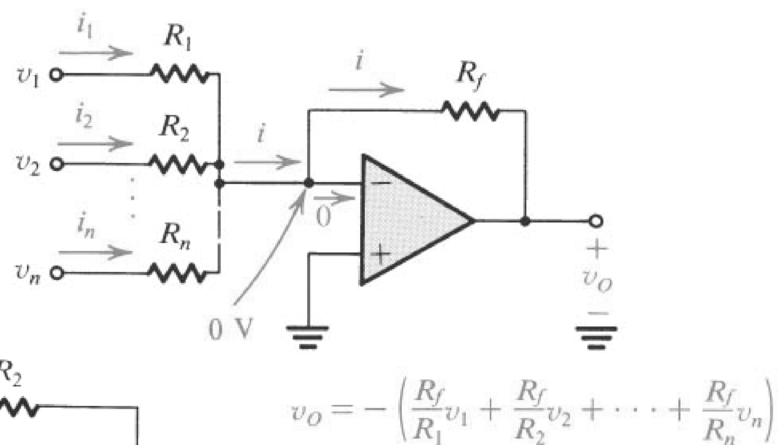
3. Inverting amplifier =>

$$v_o = -\frac{R_2}{R_1} \cdot v_i$$



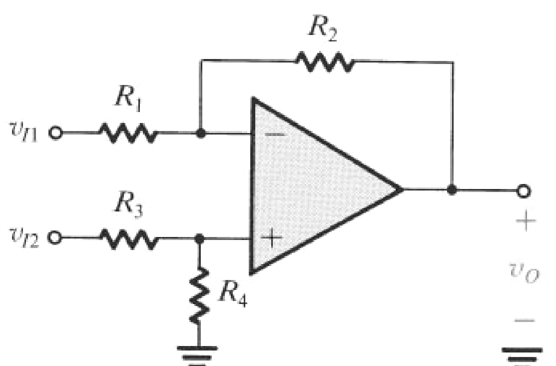
4. Summer =>

$$v_o = -\left(\frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2 + \frac{R_f}{R_3} v_3 + \cdots \frac{R_f}{R_n} v_n\right)$$



5. Differential Amplifier =>

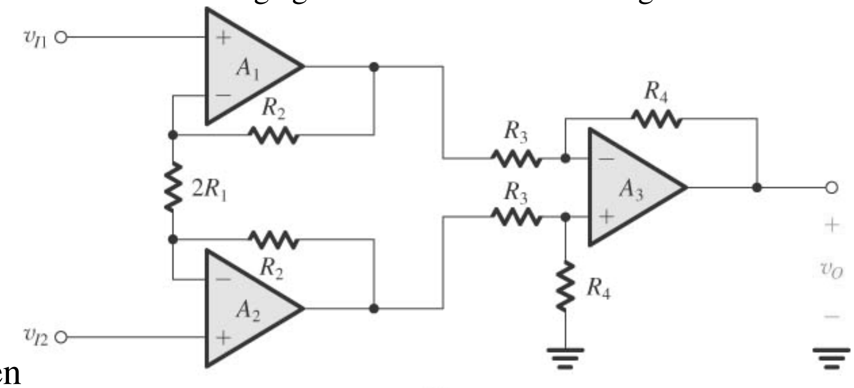
$$v_o = \left(\frac{R_2}{R_1}(v_2 - v_1)\right)$$



6. Instrumentation Amplifier =>

* This amplifier configuration can have large gain because of the two stages. Lower noise

$$v_o = \left(1 + \frac{2R_2}{R_1}\right)\left(\frac{R_4}{R_3}(v_2 - v_1)\right)$$



(b)